PRIMER ON

BIOPRODUCTS

POLLUTION PROBE
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BIOCAP
CANADA

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POLLUTION PROBE IS A NON-PROFIT CHARITABLE ORGANIZATION THAT WORKS in partnership with all sectors of society to protect health by promoting clean air and clean water. Pollution Probe was established in 1969 following a gathering of 240 students and professors at the University of Toronto campus to discuss a series of disquieting pesticide-related stories that had appeared in the media. Early issues tackled by Pollution Probe included urging the Canadian government to ban DDT for almost all uses, and campaigning for the clean-up of the Don River in Toronto. We encouraged curbside recycling in 140 Ontario communities and supported the development of the Blue Box programme. Pollution Probe has published several books, including *Profit from Pollution Preventio*n, *The Green Consumer Guide* (of which more than 225,000 copies were sold across Canada) and *Additive Aler*t.

Since the 1990s, Pollution Probe has focused its programmes on issues related to air pollution, water pollution, climate change and human health, including a major programme to remove human sources of mercury from the environment. Pollution Probe's scope has also expanded to new concerns, including the unique risks that environmental contaminants pose to children, the health risks related to exposures within indoor environments, and the development of innovative tools for promoting responsible environmental behaviour.

Since 1993, as part of our ongoing commitment to improving air quality, Pollution Probe has held an annual Clean Air Campaign during the month of June to raise awareness of the inter-relationships among vehicle emissions, smog, climate change and human respiratory problems. The Clean Air Campaign helped the Ontario Ministry of the Environment develop a mandatory vehicle emissions testing programme, called Drive Clean.

Pollution Probe offers innovative and practical solutions to environmental issues pertaining to air and water pollution. In defining environmental problems and advocating practical solutions, we draw upon sound science and technology, mobilize scientists and other experts, and build partnerships with industry, governments and communities.

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CLEAN AIR. CLEAN WATER.

BIOCAP CANADA FOUNDATION IS A NOT-FOR-PROFIT ORGANIZATION THAT has been working with industry and producer groups, government and non-governmental organizations as well as the national research community and university funding agencies to promote and encourage university-based research aimed at:

- Reducing greenhouse gas (GHG) emissions (especially N_2O and CH_4) from biological sources including agriculture, landfill sites and wetlands;
- Removing atmospheric carbon by enhancing biosphere carbon sinks in agriculture, forestry and wetlands; and,
- Replacing or complementing existing fossil energy sources with biomass to provide a sustainable and renewable source of energy, chemicals and materials.

BIOCAP's mandate is to ensure that Canada's university research community makes an optimal contribution to a national research effort focused on the sustainable use of the biosphere to manage greenhouse gases and provide a source of energy, chemicals and materials.

BIOCAP has been building a network of 10 national research networks within four major areas of study — Forestry and Natural Ecosystems, Agriculture, Bioproducts and the Human Dimensions. Since January 2002, BIOCAP has invested or committed $5.7 million to initiate more than $20 million of high quality, peer reviewed research involving over 130 researchers and 180 students in 20 universities from eight provinces of Canada. This work is helping Canadian governments, industry and land-owners better understand how the nation's vast biosphere can be use to "Capture Canada's Green Advantage" in the fight against climate change.

BIOCAP
CANADA

NOVEMBER 2004

This *Primer on Bioproducts* is an introduction to biology-based industrial products and processes — technologies and processes that use plants, micro-organisms and their products as an alternative (or as a complement) to the fossil fuels and petrochemicals used in cars, factories and consumer goods. For the purposes of this Primer, bioproducts refer to commercial, industrial and environmental products, but not to the food, feed and fibre we traditionally derive from microbial and plant species.

The Primer is written for lay readers who have a limited knowledge of biology and industrial engineering. It provides a general description of the evolving science and technology used to make bioproducts in Canada. For more detailed information, readers should contact the organizations listed in Chapter 7 and explore the references listed at the back of this document.

The goal of the Primer is to make readers aware of bioproducts and to highlight the important issues raised by biobased production technology. These issues are framed by questions about both the potential risks and the benefits of bioproducts. Many of these questions have yet to be fully acknowledged and addressed either by scientists or by policy makers. The Primer does not treat these issues in depth, and it does not advocate particular solutions. Readers who want to become actively involved in the public debate about industrial bioproducts in Canada are encouraged to contact the relevant agencies and organizations.

This Primer is available to be downloaded free-of-charge from the websites of both Pollution Probe (www.pollutionprobe.org/Publications/Primers.htm) and the BIOCAP Canada Foundation (www.biocap.ca). Printed copies can be purchased for a small fee. The Primer may be read in conjunction with other complementary Pollution Probe Primers, including those on renewable energy technologies and climate change. The BIOCAP website also contains reports on the biobased economy and Canada's biomass that may be downloaded free-of-charge.

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Pollution Probe and BIOCAP Canada Foundation are solely responsible for the contents of this publication.

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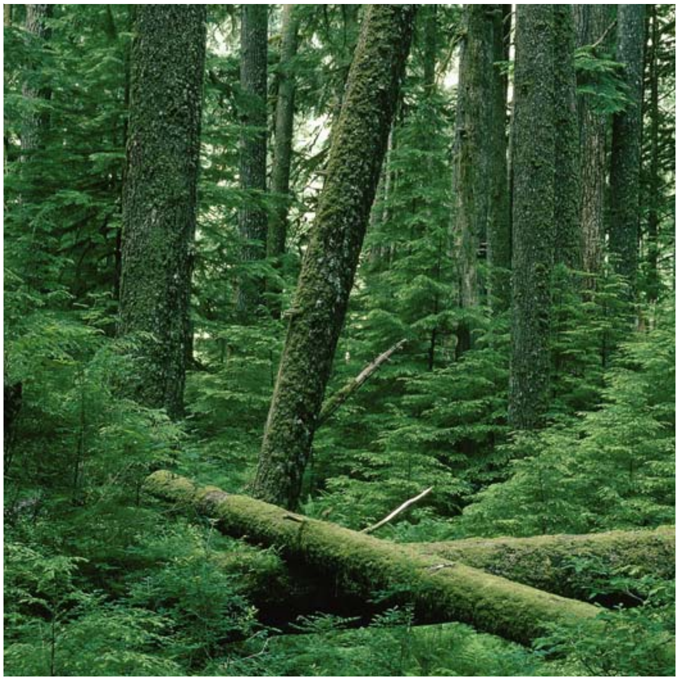
TABLE OF CONTENTS



Introduction

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Introduction

Canada is home to seven per cent of the Earth's land mass, 10 per cent of its forests and 15 per cent of the world's fresh water. The country includes large tracts of arable cropland. It is bounded by the world's longest coastline and by the waters of the Great Lakes and the St. Lawrence River.

Canada's vast geography and abundant biological resources could become dependable renewable sources of energy, chemicals and raw materials in the production of **bioproducts**. Bioproducts could also represent an opportunity to make Canadian industry and communities less dependent on non-renewable fossil fuels, which come with related environmental problems.

The potential of bioproducts is being evaluated by Canada's federal, provincial and municipal governments, and some university, industry and environmental organizations. Many experts believe that bioproducts could help reduce smog, improve the economies of rural communities and First Nations peoples, and lessen Canada's dependence on imported oil. On the other hand, others are concerned that the development of bioproducts might lead to the overexploitation of natural resources, decimation of forests and degradation of farmlands.

This *Primer on Bioproducts* is an introduction to commercial, industrial and environmental bioproducts in Canada (not including the food, feed and fibre we get from traditional uses of crops and trees). It highlights prominent bioproduct technologies under development and identifies key issues that might arise in the development of this growing Canadian industrial sector.

The document has seven chapters. Chapter 1 introduces bioproducts. It describes some of the familiar products that can be manufactured using **biomass** (i.e., plants, animals and other organisms) to replace or complement conventional manufacturing using fossil fuels and petrochemicals. This chapter also provides an overview of the ways bioproducts are made and highlights some of the issues that bioproduct technologies might raise for Canadians.

Chapter 2 puts bioproducts in perspective. Forest products, for example, are one bioproduct that already represents a significant part of the Canadian economy. This chapter discusses bioproducts that have already been developed, those that are different from "traditional" biology-based products, and novel products we may see in the future. It describes both the Canadian industrial context and the advances of other nations in this area.

Chapters 3, 4 and 5 introduce readers to prominent bioproduct and bioprocessing technologies and explore ways these could change the way we live and do business in Canada. These chapters describe how plants and other organisms can be used to help generate energy and make chemicals, plastics and other materials.

Chapter 6 introduces readers to some of the prominent and pressing issues raised by the development of bioproducts in Canada. It examines environmental, social and economic considerations that Canadians are being asked to think about now and into the future.

Finally, Chapter 7 provides information on where to find out more about bioproducts and ways you can become involved.

A glossary of terms is included to define any technical terms and phrases used in this Primer. **Bold-faced text** in the document indicates the first reference to a term that is defined in the glossary.

Chapter 1

Photo: Corel Corporation

Chapter 1

What are Bioproducts?

Biomass is any type of **organic** material that is available on a renewable or recurring basis. It includes such things as crops and trees, wood and wood wastes, aquatic plants and grasses. Bioproducts are products that are made from biomass.

Until 200 years ago, most of the world's demand for energy and materials was met by using biomass. For example, people burned wood and peat to cook and heat their homes, and they used plant and animal matter to make tools, clothes and dyes.

This dependency on biomass often led to serious environmental problems. Forests in many countries were decimated, plant and animal **biodiversity** decreased, and smoke from wood fires caused significant air pollution. Similar trends can be seen today in developing countries that rely on biomass for energy

Pervasive Petroleum

Fossil fuels are ubiquitous in our everyday lives. For instance, according to the US Energy Information Administration, they comprise more than 85 per cent of the world's primary energy supply. In Canada, oil products are used to fuel cars, homes and factories. They also provide the raw material for many different commercial and manufacturing industries. According to the Canadian Electricity Association, fossil fuel-powered thermal generators supply about 28 per cent of the electricity we use.

Petroleum also plays a key role as a critical ingredient in many products. Early in the 20th century, petroleum-derived chemicals were used to make rayon — the first human-made fibre. These chemicals are now present in many fabrics, such as nylon, polyester and elastic. The plastics used in computers, medical components, kitchen utensils and upholstery are also produced using chemicals derived from petroleum and other fossil fuels.

In contrast, bioproducts use renewable biomass as a complement or alternative to non-renewable petroleum-based **feedstocks**. The use of bioproducts could reduce our dependence on fossil fuels as a source of raw materials in the manufacturing and processing of many industrial products.

and materials. The use of biomass by industry today must include ways to avoid these problems and ensure that the industrial use of biological materials is clean and sustainable.

Bioproducts today include everything from electrical power and liquid fuels to products, such as shampoos, plastics, fabrics and solvents. They are manufactured using energy, chemicals or processes derived from biological materials (living organisms and dead matter).

In large measure, they come from forestry, agricultural and aquatic sources. They may or may not involve the use of advanced technologies, such as **genetic engineering**. For the purposes of this Primer, bioproducts refer to household, commercial and industrial products, but not to the food, feed and fibre we currently get from traditional uses of crops and trees.

The term "bioproducts" refers to a wide array of industrial and commercial products that are characterized by a variety of properties, compositions and processes, as well as different benefits and risks. Thus, the term "bioproducts" is one of convenience; a careful consideration of bioproducts requires an examination of the characteristics of particular bioproducts and the issues they raise on a case-by-case basis.

Bioproducts are important to us because the biomass used in their manufacture provides either a complement or an alternative to petroleum and **petrochemicals**. Unlike fossil fuels, biomass is renewable and has the capacity to quickly replenish itself using energy from the sun.

Why Bioproducts Now?

In the past 50 years, our understanding of the world and its various life forms has changed in profound ways. Science and technology are moving at a rapid pace and improving our knowledge of biology at the molecular level. Developments in the biological and life sciences, as well as **thermo-chemistry**, have led to discoveries of new ways to break down and use biological materials. Research is making possible new industrial products and processes that use biomass instead of fossil fuels.

From these new methods and materials, biobased fuels, bioplastics and biobased health products are emerging. These bioproducts could mark the beginning of a shift to a **biobased economy** that eventually relies on renewable biological materials to supply energy, chemicals and other products.

Associated with this shift is an increasing interest by academia, industry and governments in exploring whether a biobased economy could offer Canada an opportunity to build on our existing resource strengths and industries, while reducing pollution and enhancing economic development in rural areas.

Scientists and governments around the world are concerned about gases generated from the use of fossil fuels. These gases (including billions of tonnes of **carbon dioxide**, or CO_2) prevent heat from leaving the Earth's atmosphere and are causing global climate change, the effects of which include rising temperatures and increasingly severe weather. Scientists have come to recognize the important role that plants play in absorbing and regulating the concentration of global **greenhouse gases**.

Industry and governments are examining whether a Canadian biobased economy — one developed to minimize the adverse environmental and social impacts of bioproducts — could help reduce our overall greenhouse gas **emissions**. Thus, the use of

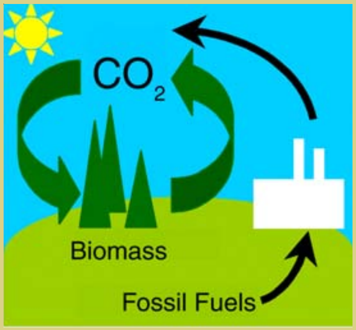
Biomass

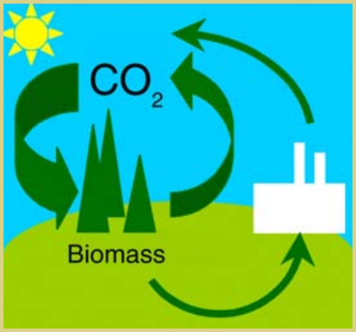
Each year, according to estimates by Stanford University biologist Peter Vitousek and his colleagues, approximately 224 billion tonnes of new biomass (by dry weight) are generated by photosynthetic plants worldwide. Biomass currently provides about 15 per cent of the energy used by people around the world and meets 35 per cent of the energy needs of developing countries. In Canada, millions of tonnes of biomass are harvested every year as trees and crops from forests and farms. While biomass currently supplies just six per cent of Canada's primary energy demand, the BIOCAP Canada Foundation estimates that, if collecting and processing it were feasible, the amount of unused biomass left on fields and forest cut sites after harvest could supply 27 per cent of the energy we now get from fossil fuels.

Bioproducts and the Carbon Cycle

One of the most important differences between bioproducts industries and fossil fuel-based industries is the relationship each of these has with the **carbon cycle** and, in particular, the trapping of energy from the sun through **photosynthesis**.

The carbon cycle refers to the flow of **carbon** — a common chemical element crucial to the chemistry of life — from an inorganic state to an organic state (i.e., biomass) and back again.





Using energy-rich biomass to "close" the carbon cycle.

bioproducts in Canada's energy and transportation industries (e.g., electricity generated using biomass fuels, or automobile fuels made from plants) can be useful in the fight against climate change.

Where Are Bioproducts Found?

Although many consumers may not realize it, bioproducts are present in most Canadian households.

For instance, wood is a traditional bioproduct that people have been using in fires to heat homes and cook meals for thousand of years. Today, many forest companies use wood residues to generate heat and electrical power for their own operations.

Other, less traditional products of biological materials and processes — now available or under development — include some types of shingles, insulation, plastics, carpet, linoleum, fibreboard, specialty paper, fabric, packaging, cleaners, solvents, paints, shampoo, cosmetics, soap, lubricants, detergents and **biofuels**, such as bioethanol and biodiesel.

Fuel ethanol made from the starch of corn is a bioproduct that is becoming a common feature at gasoline pumps. More than 600 service stations across Canada now offer fuel with bioethanol blended in as an additive. Technology to improve the acquisition of fuel ethanol from corn and other **cellulose-based** material is advancing rapidly. This would allow the use of waste agricultural and forest biomass without detracting from the use of the material as a food source.

Corn and other plants, such as wheat, that are rich in starch may also become the source of wax used to polish cars, or they may become ingredients in the glue used in home renovation projects.

Source: Bioproducts Canada Inc.

Hemp, a plant long outlawed because of its close relatedness to marijuana, is used as an ingredient in clothes, cosmetics, moisturizers and lotions. It could also be blended into the plastic of interior car door panels and dashboards to make them stronger and more durable.

Bioproducts and the Carbon Cycle — *continued*

Carbon dioxide (CO_2) is the inorganic form of carbon that is incorporated into living organisms through photosynthesis, a process that stores energy from the sun in carbon-based molecules within the biomass of vegetation and other organisms. Our bodies get carbon and the energy it stores by eating plants and the animals that eat plants.

Today, most societies get the energy and chemicals they need from fossil fuels — oil, coal and natural gas. These come from ancient plant material and other biomass that has been **sequestered** underground and away from the active carbon cycle for many millions of years.

When we use fossil fuels, we open the active carbon cycle to an additional source of carbon (from CO_2 emissions), throwing the natural cycle off-balance. The resulting increase in the concentration of CO_2 in the atmosphere has been linked to climate change.

The use of biomass, on the other hand, has the potential (if managed properly) to be a "CO_2 neutral" source of energy and chemicals, essentially closing the carbon cycle. The CO_2 absorbed by and incorporated in this biomass could be enough to offset the CO_2 generated by biomass industry processes.

Pyrolysis

Pyrolysis is a process that uses heat to decompose biomass in the absence of oxygen. Ground up biomass is exposed to temperatures of just under 500°C, converting it to char and gases. The gases are then rapidly cooled, and some of them condense into pyrolysis oil. The pyrolysis oil is a mixture of water and many different organic compounds. It can be burned as is for fuel, or can be refined to yield useful industrial chemicals and higher quality fuel. The gases that are produced during pyrolysis can be burned to create heat to keep the process going.

Bioproducts are already found in cosmetic kits and bathroom cabinets. Products from oil seeds and plant material are frequently used in the manufacture of soaps and shampoos. Algae are used to produce natural colours for use in cosmetics.

A chemical known as polyvinyl chloride (PVC) is often used as a floor covering. This petroleum-based product could be replaced by linoleum produced from plant fibres and resins. Artists' paints that once used petroleum-based azo pigments can now use dyes available in plants.

How Are Bioproducts Made?

Bioproducts are made using biomass as a raw material. Raw materials for industry can also use biomass left over from conventional agriculture, forestry and marine activities, as well as municipal works and industrial processes. The biomass may have little economic value and may be waste material that would otherwise be expensive to dispose of, such as manure and municipal **landfill** wastes. Such materials, however, become valuable as biomass. As they generate methane through microbial processing, they can be used to generate electricity.

Biomass may also be specifically grown to serve an industrial purpose. In some cases, crops and trees are selected or engineered to provide biomass of a particular quality and composition to make processing it both technologically and economically feasible.

Manufacturing bioproducts from biomass involves a variety of industrial techniques. For instance, new methods for the **thermochemical processing** of biomass (such as **pyrolysis**) are used to generate biobased oil and gas. These fuels can, in turn, be used to power electrical generators and motors. **Fermentation** is also used to make bioproducts and biofuels.

Some bioproducts do not require biomass as a raw material. Instead, they use inorganic raw materials, but involve industrial techniques that use biological **enzymes** or microbial processing during their manufacture.

Identifying the Issues

The arrival of new bioproducts in the lives of most Canadians could go unnoticed. For example, people who add a biobased cream to their cosmetic bags, or a biodetergent to their household cleaning products, may be unaware that these products are part of a raw material and process shift by industry.

For many people, the strongest indication that Canada's industry and economy are undergoing fundamental change will be public debates in the media concerning the environmental, health, social and ethical implications of the increased industrial use of biomass and the attendant technologies used by bioproducts industries. In this regard, it is likely that negative implications about the use of biomass will also be discussed in light of continued fossil fuel use and associated pollution and climate change issues.

The appropriate use of land and water resources is an issue that has arisen from the development of industrial bioproducts. Good arable land is limited, and the question is whether we can grow crops for industry and still have enough land available to grow food. Similar questions have arisen in the forest sector. Changes in the way land and water are currently used can have environmental consequences and create conflicts among users.

Other concerns relate to conflicts about ensuring that the risks and benefits of bioproduct development are fairly distributed. Some organizations, including the ETC Group of Winnipeg (formerly the Rural Advancement Foundation International), fear that inadequate patent laws and other **biotechnology** regulations ensure that large corporations, rather than rural communities and

Fermentation

Fermentation is a process that uses **micro-organisms** to perform a chain of biochemical reactions that turn sugar into other products, such as alcohols and organic acids. Before starchy biomass sources (e.g., corn) can be fermented, the starches first need to be broken down into simple sugars. This is usually done by exposing the biomass to high temperatures after adding an enzyme to act as a catalyst. Once the starches have been broken down, a micro-organism, such as yeast, is added. The micro-organism digests the sugars and produces carbon dioxide and other compounds. The micro-organism species used during fermentation depends on the desired end product. For example, a yeast called *saccharomyces cerevisiae* is used to ferment corn and sugar cane into fuel ethanol. This is the same species that has been used for centuries in brewing and baking.

developing nations involved in the production of biomass raw materials, will disproportionately control and benefit from the development of bioproduct technologies.

Controversial forms of biotechnology, such as genetic engineering, are used in the manufacture of some bioproducts. In bioproducts industries, **gene** transfer between organisms can be used to isolate and enhance the performance of micro-organisms and their catalyzing enzymes and to increase the production capacity of trees and crops. This is of concern to some people, although not as controversial as the use of genetically modified organisms in food crops.

If old growth forests and other **ecosystems** that store large amounts of carbon are used to grow biomass crops and fast-growing trees that have lower carbon densities, then bioproducts industries — often promoted as a means to help fight climate change — could contribute to the greenhouse gas problem. Large areas of land devoted to single biomass crops for industry might also threaten biodiversity (just as monoculture farming for food presents the same risk). However, energy plantations from forest biomass may be planted on abandoned farmlands, which could reduce the pressure to harvest natural forests.

Intensive growing of crops and trees could place unusually high demands on community water supplies. Plantations of trees, however, are far less likely to compromise water supplies than are agricultural crop species or even many natural grasses and herbs. Such plantations may be a good way to make marginal lands productive. The large quantities of pesticides or fertilizer required to grow some crops could also have an adverse impact on the environment. This impact can be considerably reduced by cultivating fast-growing trees, for example, since it is usually only in the first year or two of the rotation that chemicals are used, rather than every year. For trees that are **coppiced**, pesticides and fertilizers may not be used at all.

Bioproducts concerns may be offset by the benefits of using biomass in industry. The downside of bioproducts technologies, or of biomass production, may be weighed in public debates against promises of **sustainable development**, including the use of renewable resources as industrial feedstocks, improved conservation, and various environmental, social and economic benefits.

These are just some of the issues raised by the development and use of bioproducts in Canada. They are described in more detail throughout this Primer and, in particular, in Chapter 6. The Primer does not attempt to resolve these controversies or discuss the debates in depth; instead, readers interested in learning more and engaging in public debates are encouraged to contact the agencies and organizations listed in Chapter 7.

The benefits, risks and issues raised by bioproducts make it critical that Canadians become well informed and able to participate in discussions about future directions and policies. This Primer is designed to inform the debate.

Potential Benefits and Risks of Bioproducts

Understanding bioproducts means understanding the potentials, the promises and the pitfalls associated with these products and the technologies used to produce them. The word “bioproducts” is a term of convenience that encompasses a wide range of products and processes. It is difficult to make meaningful generalizations about such diversity. Adequate consideration of the pros and cons of bioproducts may be most effective when each case is considered on its merits. The following lists of potential benefits and risks highlight some of the promises and concerns that have been identified for bioproducts.

Potential Benefits:

Environmental protection

- Reduced dependency on fossil fuels and petrochemicals.
- Less greenhouse gas emissions.
- Reduced smog pollutant and toxic chemical emissions.

Diversification of energy sources

- Use of Canada’s abundant biomass resources as a renewable feedstock.
- A source of energy from municipal waste, which reduces problems associated with municipal garbage disposal.

Use of organic byproducts and waste

- Reduced amounts of effluent and solid waste.
- Reduced contamination of air, water and soil.

Invigoration of rural communities

- Increased demand for forest, farm and aquatic products, building on regional strengths.
- Localized production and creation of jobs in rural Canada.

An Energy Resource for Developing Economies

- More widely distributed access to energy, especially for many developing economies that have large biomass reserves.
- Biomass processing technologies could be an export opportunity for Canada.

Potential Risks:

Environmental threats

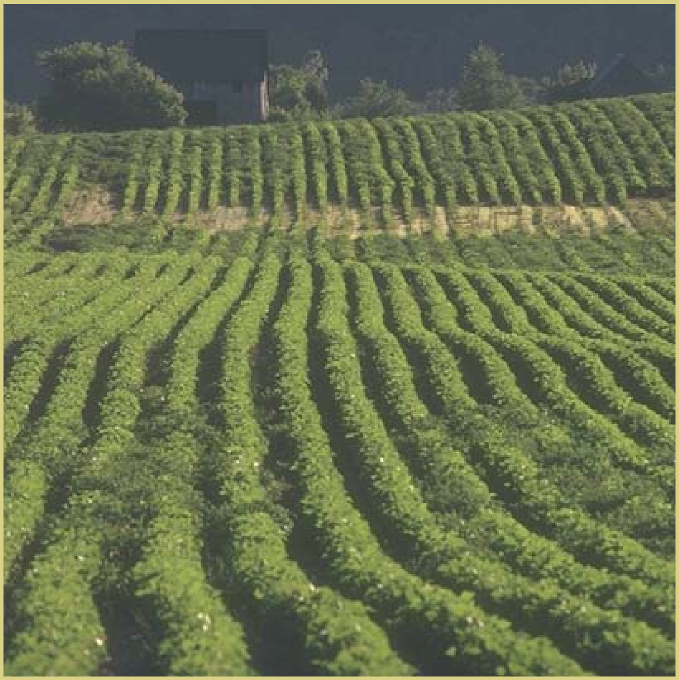
- Depleted biomass carbon stocks, increased atmospheric CO_2 concentrations and contribution to climate change.
- Reduced biodiversity.
- Increased demand for fertilizers, herbicides and pesticides, thus increasing pollution and greenhouse gas emissions.
- Some crops and micro-organisms are genetically engineered to produce bioproducts. These require full regulatory analysis to avoid negative effects on ecosystems.
- Fast-growing, monoculture tree plantations could be more susceptible to disease, or could deplete local water supplies.
- Industrial cultivation of favoured species could threaten biodiversity.
- Increased particulate carbon emissions (soot) from wood burning.

Land use and water use conflicts

- Use of land needed to supply food crops.
- Use of land and water for biomass production that should be protected or reserved for other uses, such as wildlife habitat.

Some Examples of Bioproducts

Product	Biological Raw Material	Replaced Petroleum-based Raw Material
Electrical power	Wood, plant fibres	Coal, oil, natural gas
Diesel fuel	Vegetable oils, animal fats	Diesel fuel from oil
Automotive fuel	Ethanol from starch or cellulose	Gasoline from oil
Gas heating	Methane from animal or municipal waste	Natural gas (mostly methane)
Steel	Charcoal or oil from wood to reduce iron ore	Coke made from coal to reduce iron ore
Plastics	Polylactic acid from starch	Polyethylene
Floor covering	Cork, jute, flax	Polyvinyl chloride
Textiles, fabric	Hemp, flax, other plant fibres	Polyesters
Insulation	Straw, protein glue	Polystyrene
Hydraulics, lubricating oil	Plant oils	Mineral oils
Wood glazes	Plant resins, oils	Polyacrylates, glycols
Fibre-reinforced materials	Hemp fibre, shellac resin	Carbon fibre, polyamide
Artist's paints	Plant dyes	Azo pigments



Chapter 2

Photo: Corel Corporation

Chapter 2

Bioproducts Today

Until the 1920s, most Canadian industries depended on renewable biological resources, such as trees, crops and other forms of biomass, to manufacture products. These early bioproducts industries were largely displaced as new industrial technologies made energy, plastics and other materials from fossil fuels more efficient and economical to produce. As the population and the economy grew during the past century, industrial growth fed by fossil fuels followed. So, too, did major advances in technology, medicine, food production and, for many, quality of life.

Canada’s early dependence on renewable, biological resources, such as trees and crops, was far from environmentally benign. Large tracts of forests were lost. Biodiversity suffered. Burning biomass scattered ash, smoke and other pollutants across the landscape.

Canadian Forest Products

The Canadian forest products industry is an important industry that has always used biomass. Canada exports more forest products than any other nation in the world. According to figures compiled by the Canadian Forest Service, in 2002 the Canadian forest industry exported almost $43 billion worth of products and was the nation's largest industrial employer. The industry is also considered the most geographically dispersed industrial employer in the country, supporting more than 300 rural communities.

This Primer does not consider traditional forest products (e.g., timber, pulp and paper); instead, it focuses on bioproducts that have the potential to complement or replace products currently made from petrochemicals and fossil fuels. This does not mean that Canada's forestry industry has no role to play in the development of a bioproducts industry. On the contrary, trees are essential as a source of biomass for both traditional and novel bioproducts. Several forestry companies already use branches, bark and other wood waste from their operations to generate electricity for their own operations. For example, Pacifica Papers of British Columbia — a producer of 1,300 tonnes of newsprint and other products per day — uses bark from its stone-ground wood mill and other wood residues to run a 40-**megawatt** generator that powers its facilities.

The switch to coal, oil and other fossil fuels did not solve the environmental problems. As the industrial use of these petroleum products increased they began to affect the quality of air, land and water, as a growing population generated more demand for industrial products. The large scale of industrial and other emissions has resulted in normally valuable atmospheric gases, such as CO_2, becoming global environmental problems.

Scientific advances in chemical processing and biotechnologies are making biomass a cleaner alternative to fossil fuels in the manufacture of many fuels, chemicals and materials. For example, the industrial use of enzymes to economically convert cellulose in the tough, woody parts of plants into burnable ethanol fuel has only recently been developed. Advances in thermochemical engineering, meanwhile, have improved our ability to convert biomass into gas and oil, and to make diesel fuel from vegetable oils and animal fats.

Bioproducts in Canada

Based on data collected in 2001, a preliminary study by Statistics Canada has yielded some information on the Canadian bioproducts industry. There are 81 Canadian companies involved exclusively with bioproducts. The annual activity within these companies has been estimated to involve revenues of at least $400–500 million, employment of 1,200–1,500 people, and research and development funds in the range of $60–80 million. In addition, another 52 Canadian companies are involved in bioproducts on a more limited scale.

More than 80 per cent of the bioproducts companies in Canada are small- and medium-sized enterprises. The number of enterprises continues to grow (but the number reported may not be completely representative since some bioproducts are also manufactured by firms not recognized as biotechnology companies in the Statistics Canada survey). In 2004, 223 Canadian bioproducts companies were included in a guide and directory to the industry published by Contact Canada (http://contactcanada.com).

Some Canadian bioproducts manufacturers are subsidiaries of large corporations. One example is Dow Bioproducts of Elie, Manitoba, a wholly owned subsidiary of Dow Chemical Canada that makes construction materials out of straw and resin. Other large corporations, such as DuPont, BASF, CASCO and Cargill Dow, are investing in bioproducts. Most Canadian bioproducts manufacturers, however, are small corporations, such as Canolio Inc. of Quebec. Canolio makes body creams and massage oils from hemp. Other current examples of Canadian bioproduct companies include Iogen, Natunola, Wellington Polymers, Ensyn, Tembec, Nstarch, BioTerre Système, Hempline, Biox Corporation, Dynamotive Energy Systems, Linnaeus Plant Sciences, and Robustion.

According to Statistics Canada, in 2001 Canadian industry invested $60–80 million in the research and development of bioproducts — a significant sum, but considerably less than investments in the United States, Japan and Germany. The Canadian government has also had a growing interest in bioproducts and biobased energy production. In 2001, a federal "Inter-departmental Working Group on Bioproducts" was established to coordinate the efforts and initiatives of different federal departments, including the *promotion* of biotechnology by Industry Canada, Environment Canada, Natural Resources Canada, and Agriculture and Agri-Food Canada, as well as the *regulation* of biotechnology by Health Canada. Similarly, Industry Canada, along with a variety of industrial stakeholders and interest groups, has developed a technology roadmap on bioproducts and bioprocesses that recommends more investment by the federal government to advance biomass as an alternative to petroleum resources.

Source: Corel Corporation

Meanwhile, bioproducts advocacy associations, such as BioProducts Canada Inc. and its regional and provincial counterparts, have emerged nationally to encourage investment in, and a greater emphasis on, bioproducts by governments and industries. Other national non-government groups, such as the BIOCAP Canada Foundation, encourage research, development and commercialization in this area.

What Other Nations Are Doing?

According to the US Department of Energy, interest in bioproducts is developing steadily around the world. Sales of bioproducts in the United States more than doubled between 1983 and 1995, from $5.4 billion to $11 billion. In 1999, a White House Executive Order committed the United States government to a three-fold increase in its current use and production of bioproducts and biofuels from biomass by the year 2010. In 2002, the US Department of Energy published its *Vision for Bioenergy & Biobased Products in the United States*, which recommended that government and industry work to increase the share of biomass power to five per cent, transportation fuels to 20 per cent, and biobased products to 25 per cent of their respective markets by 2030.

Japan is also encouraging growth in bioproducts research and industrial development. Recently, bioproducts were identified as one of three key biotechnology initiatives aimed at transforming conventional industry into industry that is based on cleaner, less greenhouse gas-intensive biological processes and products.

Germany is a leader in developing a suite of programs, product standards and regulatory frameworks designed to promote the use of renewable fuels, chemicals and materials, as well as the development of environmentally friendly industrial processes.

Brazil requires vehicles to use gasoline with at least 20 to 24 per cent ethanol, which is locally produced from sugar cane. This regulation to reduce dependency on foreign oil has resulted in as much as 40 per cent of Brazil's vehicles being powered by 100 per cent ethanol. The government is also encouraging the country — now the world's largest ethanol producer — to seek export opportunities.

Scandinavian countries, meanwhile, are actively encouraging the planting of fast-growing poplars and willows to make paper products and composite construction materials.

Chapter 3

Photo: Corel Corporation

Biofuels and Bioenergy

Canada's potential for producing fuels and generating energy from biomass is both very large and underutilized. However, the feasibility of using biomass as a source of fuel for cars, factories and electricity generation depends on the availability of appropriate technologies and the harvesting of sometimes remote biomass resources. Currently, Canada meets about six per cent of its total energy needs from biomass, compared to three per cent for both the European Union and the United States.

Technologies through which biomass can be converted into fuels and energy include **fermentation**, **combustion**, **anaerobic digestion**, **pyrolysis**, **thermal depolymerization** and **gasification**. Some of these technologies and related processes are described below to show how they work.

Does Canada Have a "Green Advantage"?

Canada is home to seven per cent of the world's land mass and 10 per cent of its forests. Most of the country's biomass production takes place in large forests.

The BIOCAP Canada Foundation estimates that, if gathering and processing this widely distributed energy resource were economically feasible, there may be enough unused biomass from Canada's forestry and farming operations alone (crop residues, unused tree branches, mill waste, etc.) to provide almost 27 per cent of the country's current energy needs. The university-based research organization also calculates that a 25 per cent increase in today's tree and crop production could meet a further 15 per cent of the energy demand now being filled by fossil fuels.

These numbers reflect the total biomass potential of Canada's vast forests and farmlands. They do not take into account the difficulties associated with collecting this material, the shortcomings of the technology, the economics of processing it, the related pollution problems, and other environmental and economic issues associated with the use of biomass as a source of energy.

Biomass for Heat and Power

Burning biomass is called "direct combustion." Woodstoves and fireplaces use direct combustion to heat homes. Traditional stoves and fireplaces may be the oldest and perhaps crudest means for converting biomass to heat, but new technologies have made many wood and biomass burning stoves very efficient. Fuel for these stoves includes everything from wood and wood chips to biomass particles, pellets and fire logs made from coffee grinds. While the amount of trace gases (including CO_2) and particles emitted from woodstoves varies widely among different models, many Canadians use them as an alternative to oil and gas furnaces for space heating, or to fossil fuel-fired plants as a source of electricity.

Biomass direct combustion is also used to generate steam and electricity (or, more simply put, heat and power). For this purpose, dried organic material is burned to boil water, and the resulting steam provides process heat that forces a **turbine** to spin and generate electricity. In the United States, direct biomass combustion currently generates more than 7,500 megawatts of electricity — enough to power several million households.

In Canada, direct combustion is used to generate heat and electricity in communities across the country. For example, in Charlottetown, Prince Edward Island, a wood-fired district heating system has been supplying heat to 15 buildings since 1986, including provincial government buildings, city hall, two churches, three hotels and a fire hall.

Hydro-Québec gets 28 megawatts of power from the wood-fired Chapais Generating Station in Chapais, Quebec. The Williams Lake power plant in Williams Lake, British Columbia, burns wood waste from forestry operations in the area to fuel its 60 megawatt operation. In the Town of Ajax, a biomass-powered district energy system provides energy to the community centre, Ajax-Pickering Hospital, the Ajax Works Department and more than a dozen industrial customers.

Most biomass can generate energy from direct combustion, but some biomass sources are avoided because they produce large amounts of ash that can foul boilers, reduce efficiency and increase costs. Similarly, wet biomass can result in a large amount of energy being wasted in boiling off the moisture before the biomass can be burned.

Biomass can also be converted into clean and efficient fuels that can be indirectly used to drive generators, **fuel cells**, engines and other energy conversion devices, and to produce power. Pyrolysis and advanced gasification technologies transform organic materials into crude oil (bio-oil) and "synthesis gas" (**syngas**), respectively. Thermal depolymerization produces true hydrocarbon oil comparable to high-quality heating oil. These technologies generally have greater conversion efficiency and use a wider variety of biomass than combustion technologies.

Pyrolysis converts biomass to fuel by heating it in an oxygen-free tank. The gas produced is then quickly cooled to a liquid and a solid charcoal. The liquid can be burned for energy or used to produce chemicals that can replace petrochemicals. Renewable fuels produced by pyrolysis can be more easily stored, transported and burned than can solid biomass.

Source: Corel Corporation

Gasification is a similar process to pyrolysis, but introduces oxygen as the biomass is heated. The result is a cleaner fuel called syngas. Syngas contains carbon monoxide and hydrogen, as well as nitrogen, but it still burns with fewer emissions than do fossil fuels. Syngas can be used in place of natural gas to generate electricity, or as a raw material to produce chemicals (e.g., ammonia) and liquid fuels (e.g., methanol).

Co-firing is another method of reducing gas emissions and the environmental impacts of fossil fuel-powered generators. Rather than heating the generator boilers in electricity plants with coal alone, the co-firing process mixes dried biomass into the fuel. Co-firing helps reduce the amount of coal needed to produce electricity.

Processes for producing electrical power from renewable biomass (and from other renewable energy sources) are described in Pollution Probe's *Primer on the Technologies of Renewable Energy* (see www.pollutionprobe.org/Publications/Primers.htm).

Biomass to Fuel Vehicles

People have been fermenting plant sugar into ethanol almost since the beginning of recorded history. New biotechnologies have sped up these processes. Today's novel enzymes make it possible to generate alcohol from plants several thousand times more efficiently than the earliest brewers and distillers managed it. Ethanol burns quickly and cleanly and can serve as a renewable fuel for transportation and other uses. Most of the ethanol fuel now available in Canada is produced from corn. The starch in the corn is chemically processed into glucose (a simpler sugar), which, in turn, is fermented into alcohol using **yeast**. About 225 million litres of ethanol is now blended into gasoline (as a five to 10 per cent additive) and sold at more than 600 retail stations across Canada each year. In October 2000, the federal government announced plans to increase ethanol production in Canada by 750 million litres per year over the next five years, which would increase bioethanol production from about 0.6 per cent to 2.5 per cent of the total gasoline use in Canada. Canadian ethanol production currently consumes more than 17 million bushels of corn every year. One major byproduct of this ethanol production is a high-quality livestock feed that is more nutritious than the original corn.

The cost and availability of suitable crops are considered major hurdles to the larger commercial development of bioethanol in Canada. Additionally, the environmental benefits of converting corn and grain to ethanol (e.g., lower greenhouse gases) can be compromised by the large amounts of energy, fossil fuels and fertilizer needed to farm these crops.

New biotechnology that is promising large-scale conversion of the tough, fibrous parts of plants (i.e., the **cellulose** in stalks, corn cobs and straw) to bioethanol may be more

Source: National Biodiesel Board. www.biodiesel.org.

environmentally attractive than current technologies. Many of the technologies needed to manufacture cellulose-based ethanol on a commercially viable scale are still in development. Iogen Corporation of Ottawa has become a world leader in the development of this technology.

Meanwhile, fatty acids or oils from renewable plant and animal sources can be converted into a clean-burning fuel known as **biodiesel**. These organic oils — from seeds, corn, canola, animal fat, and even "used" fast-food-fryer vegetable oil — can be separated to isolate the combustible compounds that make up the fuel. According to the Canadian Renewable Fuels Association, biodiesel, as a blend or by itself, can be used in conventional diesel engines to significantly reduce some pollution emissions. Producing the fuel does not generate any net CO_2 emissions, and the fuel itself is considered to be **biodegradable**.

Gas from Municipal and Farm Waste

Biogas — a mixture of methane and CO_2 — is a renewable fuel that can be produced from organic waste. Biogas is made by **bacteria** that degrade biological material in the absence of oxygen in a process known as anaerobic digestion. Anaerobic digestion can result in the creation of gas from organic material. It usually occurs naturally in marshes, rubbish dumps, septic tanks and the digestive systems of ruminants, such as cattle and sheep.

The disposal of farm manure and municipal solid waste presents serious environmental problems and expense for rural and urban communities. Instead of being disposed, these wastes can be used in the production of biogas. Anaerobic digestion processes have been applied to poultry and cattle manure, hog farm effluent and food processing waste. Biogas from a number of landfill sites in Canada is now used to drive gas turbines for power generation.

Fuelled by Biodiesel

Costs are still a significant barrier to large-scale commercial production and use of biodiesel. Estimates by the US Department of Energy suggest that biodiesel costs from US$1.95 to US$3 per gallon (depending on the feedstock and the supplier), compared to the current price of regular diesel of about US$1.50. Diesel blends using 20 per cent biodiesel are expected to cost US$0.30 to US$0.40 more per gallon than diesel, the department says. An important factor here is the equalization of incentives and enabling policies for biobased products — starting with energy — that put biomass on a level playing field with fossil fuels, which are still subsidized and not held accountable for all of the environmental costs they create.

According to the American Biodiesel Association, despite the higher cost, biodiesel users in the United States already include the US Postal Service and the US Departments of Energy and Agriculture, as well as almost 100 other public and private fleets in the country.

The use of biodiesel in Canada is problematic in the winter months. In cold weather biodiesel thickens more quickly than conventional diesel. For the time being, biodiesel can be

Fuelled by Biodiesel — *continued*

used as an additive in up to five per cent of the conventional diesel fuel blend until an optimum blend ratio can be found that will improve biodiesel's winter performance.

In Canada, very little biodiesel is produced commercially; however, an increase is expected over the next few years. Demonstration projects to test the viability of biodiesel as a fuel for city transit and public works fleets have been established in a number of municipalities, including Kingston, Montreal, Saskatoon, Brampton, Guelph, Vancouver, Whistler, Halifax and Toronto. BIOX Corporation of Toronto has developed a new chemical technology that produces biodiesel from biomass at a cost 40–50 per cent cheaper than other biodiesel processes. The company is planning to launch its first commercial-scale biodiesel production facility (60 million litres per year) in 2004.

This not only makes electricity, but also burns methane — a greenhouse gas 21 times more potent than CO_2 — before it is released into the atmosphere.

The municipality of Kitchener–Waterloo, for example, together with Toromont Energy, use naturally created **landfill gases** — gases that were once simply burned off — to produce electricity. A network of subterranean pipes collects the gases from the landfill and uses them to fuel an electrical generating station.

In Lethbridge, Alberta, ECB Enviro is building a pilot facility that will produce biogas energy (as well as treated water and fertilizer) using pig farm manure generated by area hog operations. The company expects the plant, which began construction in 2003, to use 100,000 tonnes of manure per year, while generating enough electricity for about 900 homes.

Biomass as a Fuel Cell Hydrogen Source

Biomass may also have a role to play in the development of renewable hydrogen fuel for fuel cells. Fuel cells generate power by combining hydrogen fuels and oxygen (without combustion) to produce water and electricity.

Hydrogen is extremely volatile and explosive. It also takes up a lot of room relative to the amount of energy it provides, and it is difficult to store and deliver to consumers. One way around these obstacles is to use established fuels as a portable source of the hydrogen. Ethanol and methane made from biomass can be processed into hydrogen for fuel cells. Fuel-cell powered cars generate fewer tailpipe emissions and have higher fuel efficiency than standard gasoline-powered automobiles.

Fuel cells were first used commercially by NASA in the 1960s. Currently, North American automobile manufacturers, as well as many foreign auto manufacturers, are trying to develop **cost-effective** fuel-cell vehicles. For cars and other vehicles, fuel cells could mean less maintenance than for conventionally produced vehicles, and the ability to achieve up to 130 kilometres per litre of fuel (almost 10 times more efficient than the average car today).

A prototype of a car powered by fuel cells.
Source: Ballard Power Systems. www.ballard.com

Chapter 4

Photo: www.comstock.com/ca

Chapter 4

Biochemicals and Biomaterials

Industrial chemistry is the science used to make many of the everyday products and materials we take for granted — plastics, glues and cleaners, to name a few. Industry and governments looking to find cleaner, more efficient and cost-effective manufacturing methods have begun to focus on naturally occurring chemical reactions and on the biological structures that help these processes along. Their hope is that relying on natural processes will help industry reduce the hazardous chemicals used, the dangerous reactions required, and the toxic waste created.

Yet, the overall impact of these bioproducts is not clear. In a 2001 report, the Organisation for Economic Co-operation and Development (OECD) reviewed the environmental and economic performance of bioproducts industries (using life-cycle assessments) and found that, in general, bioproducts consume less energy and produce less greenhouse gases than conventionally produced products. However, the same report concluded that bioproducts are rarely superior to conventional products in all categories of environmental effects. For example, some bioproducts industries that rely on biomass can contribute to the **eutrophication** of lakes, rivers and other surface waters. Eutrophication is associated with nitrogen and phosphate run-off from fertilizers used in growing crops.

Green Chemistry

Industrial chemistry that seeks to reduce pollution, increase efficiency and limit the use of hazardous materials in the manufacture and use of chemicals is often called "green chemistry." The object of green chemistry is to create safer and more environmentally benign chemicals, as well as the synthesis processes, reagents, solvents, products and byproducts involved in their production and use. It also aims to be more chemically and energy efficient.

Green chemistry often uses biologically derived (from biomass) chemicals and materials to achieve its goals, since these chemicals are less likely to be as persistent and as toxic as petrochemical derivatives. Green chemistry has also focused on using chemical processes based on, or involving, naturally occurring biological structures, such as enzymes or the metabolic pathways of living **cells**, that are often very efficient and more likely to be environmentally neutral than other industrial chemical processes.

Biomass to Produce Industrial Products

In some cases, the chemically manufactured materials we rely on today can be readily replaced by materials found in nature. In some cases, small modifications to naturally occurring substances can yield useful, easily obtainable products.

For example, polylactic acid is a plastic material derived from renewable sources, such as the starch from wheat and corn. In the future, it will also be extracted from plant cellulose.

Source: www.comstock.com/ca

Similar to conventional fossil fuel-based plastics, polylactic acid is durable and can be shaped and moulded to create a number of useful products, ranging from grocery bags to toys. It can be used as a textile and can readily replace nylon, polyester and polystyrene.

Plastics made from petroleum products are responsible for worldwide landfill and other pollution problems. While polylactic acid plastics are also slow to degrade in the environment, work is being done to blend this material with cornstarch or resin to make it more biodegradable, according to the US Department of Agriculture. These plastics require far less energy to produce than conventional plastics. Researchers are also studying ways to produce polylactic acid from tough stems, husks and woody leftovers (i.e., cellulose) from farming and forestry.

Enzymes as Industrial Agents

Enzymes are large, organic helper molecules that assist and speed up the chemical reactions necessary for life. These (mainly) **protein catalysts** grab the chemicals involved in a reaction and bring them together, letting go again when the desired reaction has occurred.

In some cases, industry has been able to isolate these chemical matchmakers from the plants, animals and micro-organisms in which they naturally occur, and to put them to work. Enzymes can carry out very specific tasks, so enzyme-mediated chemical processes can be highly efficient. Some enzyme-mediated processes use less energy and produce less waste than conventional industrial chemistry.

Through genetic engineering or by "molecular evolution" (i.e., rapidly "evolving" enzymes through a process that imitates natural evolution and selection), industry can modify and direct the work of enzymes to help with entirely new chemical reactions or to work in specific conditions, such as high temperatures and high acidity.

Enzymes at Work

The global market for industrial enzymes is valued at more than $1 billion annually, according to the OECD. It continues to grow by about 10 per cent per year. Increasingly, enzymes are playing a pivotal role in industrial processes around the world.

Right now, for example, enzymes can often be found in laundry detergent to better remove stains. They are also used to convert cellulose to sugar, to bleach paper, to curdle milk for cheese, and to improve the consistency of flour in bread making.

Iogen Corporation (Canada) — Ottawa-based Iogen Corporation has developed an enzyme hydrolysis technology that readily breaks down cellulose — the tough, woody material found in straw, corn stalks, wood and orchard trimmings — so that it can be converted to bioethanol fuel. Ethanol from biological sources has been promoted as a fuel alternative that can help reduce the greenhouse gas emissions associated with gasoline. One problem has been that the only easy way to get ethanol from plants is to convert it from starchy plants, such as corn and grain. Iogen, which has built a substantial business developing novel industrial uses for natural enzymes, is now able make environmentally friendly fuel from the parts of food crops traditionally underused or abandoned in the fields. Iogen's demonstration-scale plant for producing "EcoEthanol" can

Enzymes at Work — *continued*

process about 40 tonnes wheat, oat and barley straw every day and has the potential to produce three to four million litres of ethanol each year.

Mitsubishi Rayon (Japan) — The Japanese company Mitsubishi Rayon uses an enzyme it gets from a naturally occurring micro-organism to help in the production of acrylamide, an important chemical used in the production of plastics. During the conventional production of acrylamide, either copper or sulphuric acid, together with very high temperatures, is needed. By using the enzyme known as nitrile hydratase, Mitsubishi Rayon has been able to produce acrylamide with greater purity at less cost and with 80 per cent less energy per unit of production than the conventional process. By genetically engineering the original organism, the company has improved both the yield and the performance of the enzyme.

Baxenden Chemicals (Britain) — An enzyme from the yeast *Candida antarctica* is the star of a process used by Britain's Baxenden Chemicals to make polyester. The company employs the bacterial enzyme to help build long polyester molecules at much lower temperatures and without use of the toxic solvents and acids that characterize the conventional process. The enzyme-mediate process is also much better than other industrial chemical processes at building the molecules to a uniform length. This makes the polyester especially valuable as hot-melt glue, such as the glues used in glue-guns.

Cerol (Germany) — Degumming is the process of refining vegetable oils to free them of unwanted "gummy" materials and to ensure high quality and a long shelf life. Using conventional methods, the oils are refined by adding acids and water to them and then separating them along with unwanted particles and contaminants using a centrifuge. Germany's Cerol uses the enzyme phospholipase during degumming to get the same result, but with a reduced need for the caustic soda, phosphoric acid and sulfuric acid used during conventional processes. The use of the enzyme also reduces the amount of water needed for washing and dilution, and cuts down the amount of waste sludge generated.

Metabolic Pathways as Industrial Agents

The metabolic pathways of an organism refer to the chemical steps a living cell takes to store or release energy. Like the enzymes that act as catalysts to make these chemical steps happen, these pathways have become very efficient over evolutionary time. Industry has been able to harness the whole cells of micro-organisms to take advantage of their metabolic pathways in the production of chemicals. By modifying the micro-organisms through genetic engineering, these cells can become highly efficient, producing higher yields of chemicals than conventional processes and without the need for multiple steps.

In Britain, for example, a chemical company called Avecia uses *Pseudomonas* bacteria (a common bacteria found in soil and water) to help make S-chloropropionic acid, an intermediate chemical used in the production of several herbicides. The bacteria isolate the pure S-chloropropionic acid molecule by breaking down its accompanying ineffective molecular twin. Using conventional chemical procedures, this would require solvents and a lot of energy. The bacteria do the job at lower cost to industry and with less waste.

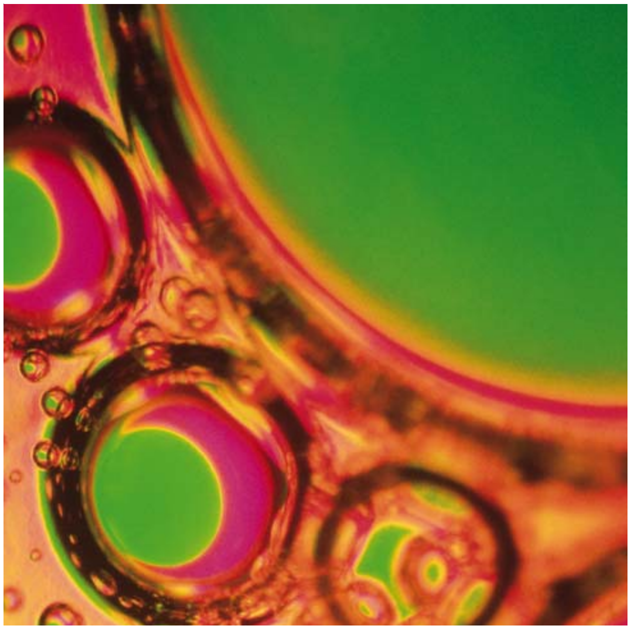
Bioprocesses for Bleaching and Leaching

The enzymes and metabolic systems of micro-organisms have also been useful in the textile, papermaking and mining industries. In the conventional bleaching and treatment of paper and fabric, for instance, large amounts of water, energy, bleach and other chemicals are needed to whiten the fibres and, afterward, to rid the product of the leftover chemicals. Enzymes from biological sources can help in the bleaching, or they can assist with washing and cleaning the material once bleaching is complete.

Iogen Corporation has been a world leader in the development of the enzyme xylanase to help with the bleaching of wood pulp for paper mills. This enzyme, originally isolated from the cells of a fungus, works by making the tough, lignin structure of the wood pulp more permeable to the bleach. As a result, less water and chlorine is required in the process. The process is also used by Domtar Inc. of Canada.

As another example, Japan's Oji Paper Co. uses the enzyme catalase to rid fabric of hydrogen peroxide after bleaching. This enzyme reduces the temperature and amount of water required to wash away the bleach.

Meanwhile, bacteria have been put to work in the mining industry. The South African mining company Billeton uses bacteria for leaching copper from the sulphide ore in which it is found. The bacteria, which works by oxidizing the sulphur and iron in the ore, saves the time, energy and expense associated with shipping the ore to a smelter to extract the copper. It also cuts emissions of sulphur oxides, arsenic and other toxic chemicals.



Source: www.comstock.com/ca

Budel Zinc of the Netherlands uses bacteria to treat the wastewater from its zinc refinery process. The sulphate-reducing bacteria capture trace amounts of zinc and other metals from the acidic wastewater and settle them out as a precipitate. The process is more successful than conventional methods for removing these contaminants from wastewater, and it avoids the build-up of heavy metal contaminated sludge that was a byproduct of the conventional process.

Industrial Ecology

Some thinkers, notably the influential United States management consultant Hardin Tibbs, believe biology can equip industry for greater production efficiency and pollution reduction by providing a model for interdependent industrial infrastructures.

Industrial ecology is the notion that groups of companies can emulate the cooperative interactions of living organisms in natural **ecosystems**. By working together, the byproducts or wastes generated by one industry can serve as the raw material for another, and so on through an industrial community, or "cluster." Groups of companies working in this manner can become far more efficient and produce far less waste than one company could on its own, resulting in industrial "ecosystems" that are more self-sustaining.

The idea of industrial ecology emerged, in part, from the notion that industry's negative effects on the environment result because it operates outside of a larger view of the planet's ecology — that is, it does not take into account the natural cycles of living things. By working together in industrial communities, industry can operate so that its byproducts and wastes, as well as its raw material demands, fit into the large-scale ecological cycles of the environment.

Chapter 5

Photo: Corel Corporation

Chapter 5

Bioproducts and Bioprocesses

This section of the Primer builds on the descriptions of biochemicals and biomaterials in Chapter 4, and looks at additional applications to bioproducts and bioprocesses.

Wood Pulping with Fungus

Traditionally, pulp is made by boiling wood chips in a chemical solution to break down the lignin and fortified cell walls of the wood. Some pulp and paper companies, such as European paper producer Leykam Austria, are now looking at using fungi (such as white rot fungus, *Bjerkandera* sp., which plays a key role in the natural rotting of fallen trees) and fungal enzymes to begin the breakdown of lignin and fibre separation of wood prior to pulping. This pre-treatment reduces the amounts of energy and chemicals needed to produce the pulp, while limiting the amount of waste. Leykam Austria has found that, as a pre-treatment for pulping, the fungal enzymes contribute to the removal of 30 per cent more lignin with the use of less chlorine bleach.

Well Drilling with Starch

The process for drilling oil wells uses a lubricating mud (a fluid mix of clay, water and oil), which also keeps boreholes open and oil deposits sealed from contaminants during drilling. The problem with this traditional concoction is that the oil used is environmentally harmful, as is the acid needed to break through the sealing layer (the "cake") of mud. A solution, once again, has been found in biology. These days, traditional drilling muds can be replaced with a mixture of starch and organically produced compounds (such as the lubricating "xanthan gum" made by *Xanthomonas campestris* bacteria). These mixtures contain enzymes, instead of acids, to remove the sealing cake. British Petroleum Exploration says its use of this biological alternative has saved money and reduced environmental damage.

Biological Sensors for Food and Security

Millions of Canadians become ill from food poisoning each year, and perhaps hundreds die from bacterial pathogens, such as *Escherichia coli* and Salmonella. Increasingly, the food processing industry is looking to biology to provide early warning systems that can signal the presence of food pathogens. In general, the systems work by using the natural protein antibodies produced by living things in response to the toxins (antigens) generated by invading micro-organisms. The antibodies are arranged in a pattern; when the antibody "key" fits the pathogen's antigen "lock," the pattern or colour automatically betrays the presence of the bacteria. These same techniques are also being developed for early detection of pollution and for defence against biological and chemical weapons.

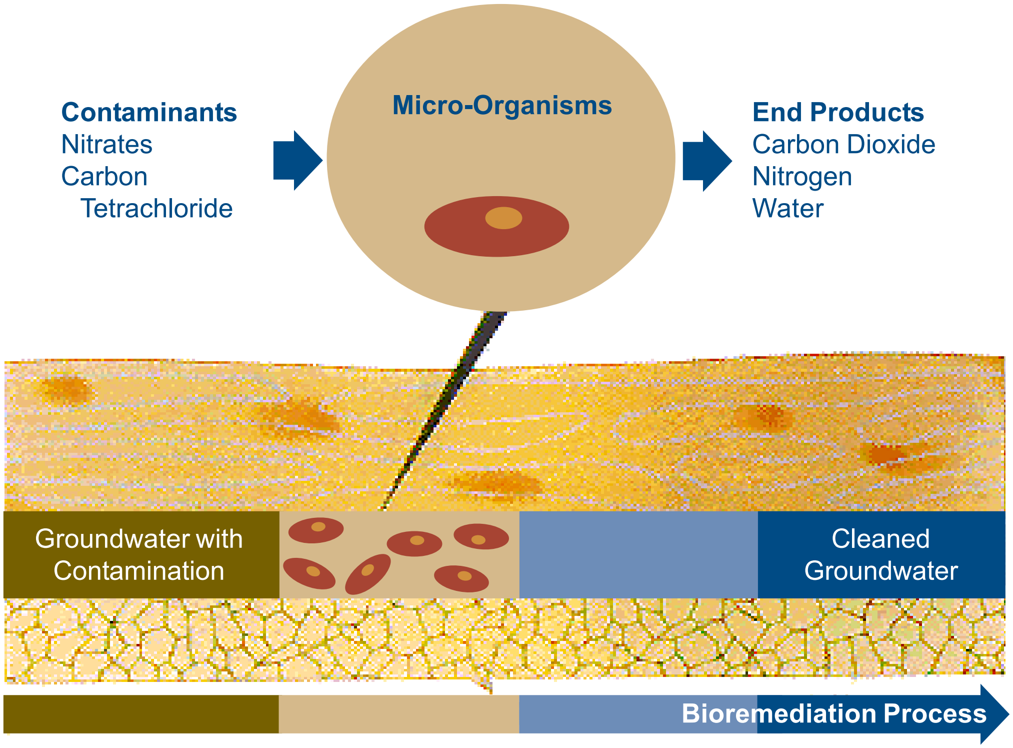
In some cases, **DNA** from pathogens and other organisms is incorporated into microscopic detection machines known as "gene chips." Gene chips combine what is known about the biology of DNA with **nanotechnology** and information technology to produce a tiny laboratory slide that automatically signals to a computer when the genes are turned "on" or "off." As with the genetic modification of bacteria, gene chips allow for instantaneous detection of pathogens, toxic chemicals and other harmful substances.

Bacteria Sniff Out Landmines

There are an estimated 60–70 million landmines buried in the fields and forests of more than 60 countries worldwide. According to the International Committee of the Red Cross, these mines injure or kill approximately 26,000 civilians every year. A few years ago, experts found a microscopic ally in their battle to rid the world of landmines. The bacterium, *Pseudomonas putida*, was found to have a natural sensitivity to trinitrotoluene — the well-known TNT used in explosives. Through transgenic engineering, scientists have genetically modified the bacterium so that it produces the same protein that jellyfish use to glow fluorescent green. The jellyfish protein is stimulated when the bacterium detects the presence of TNT. This modified, explosive-sensitive bacterium has already been shown to be very effective in detecting landmines.

Bioremediation

Spills and environmental contamination by oil and toxic chemicals are becoming ever larger threats to the environment and human health. They are difficult and expensive to clean up. However, many naturally occurring micro-organisms in soil and water eat away at fossil fuel-derived toxic compounds. These bacteria and fungi convert the contaminants into less harmful or benign compounds, such as CO_2 and water. The process of using these micro-organisms to clean up pollution is called **bioremediation**. Crude oil, gasoline, creosote, chlorinated solvents, sewage effluent, industrial effluent, agricultural chemicals and pesticides are all potentially susceptible to microbial degradation. As with bacteria and fungi, plants can also be used in bioremediation (this is called phytoremediation). Bioremediation is not limited to petroleum-based and chlorinated pollutants. The bacterium *Geobacter metallireducens*, for example, can remove uranium, a radioactive waste, from contaminated groundwater.



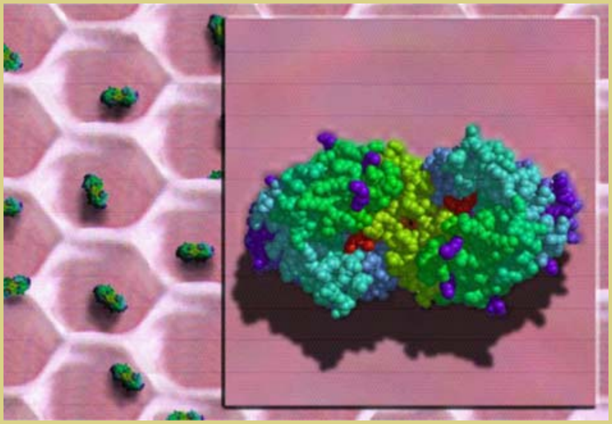
Source: US Department of Agriculture. www.nal.usda.gov/bic/bio21

Specialty Bioproducts

Occasionally, nature's cues for industry come from disparate places. Consider Montreal's Nexia Biotechnologies Inc. In its bid to make a super-strength material for bullet proof vests, medical sutures and other commercial uses, Nexia realized that some of the world's most resilient and durable fibres were being produced every day in attics and gardens around the world. It discovered that spider web silk has a tensile strength of about 135,000 kilograms per square inch and is both stronger and lighter than material based on steel or petrochemicals. Since spiders are difficult to raise in commercially useful numbers (they eat each other), Nexia soon hit on the idea of splicing the gene that codes for the spider silk protein into the DNA of a goat. The goat then produces the silk protein in its milk. The next step is extracting the protein from the milk and making it into useable fibre.

Bioproducts and Nanotechnology

Nanotechnology is the delicate science of building devices and materials one molecule, or even one atom, at a time. By understanding the world at the scale of a nanometre — one billionth of a metre, or about a hundred-thousandth of the diameter of a human hair — some scientists believe they can create microscopic machines and materials for use in industry. For example, organic proteins create complex and minute structures within living cells that can serve as molecule-scale scaffolds, cables, motors, ion pores, pumps, coatings and chemically powered levers. Similarly, biological organisms can control the construction of inorganic structures within living tissue, such as bone, teeth and the inorganic skeletons of diatoms and other algae. Biological mineralization, as the process is known, is providing nanoscientists with the tools they need to build microscopic silica structures (such as those used in the development of information technologies) or to devise better medical means of replacing and regenerating bone.



Engineered protein machines can be embedded in synthetic nanomembranes that may one day break down cellulose more efficiently or produce hydrogen for fuel cells.
Source: US Department of Energy Genomes to Life Program. http://doegenomestolife.org

Chapter 6

Photo: Corel Corporation

Chapter 6

Understanding the Issues

Governments, industry, university and other researchers are studying whether industrial bioproducts can help Canada sustainably build on its resource strengths and its existing industries while lowering greenhouse gas emissions and reducing our dependence on non-renewable fossil fuels.

At this point, many questions remain about the environmental, social, economic and ethical implications of bioproducts. These questions are difficult to answer because of the diversity and large number of bioproducts involved. Evaluating their impacts is also complicated by the complexity of the science of bioproducts, the absence of performance evaluations and life-cycle assessments for many existing bioproducts, and the amount of conflicting information available concerning several bioproduct technologies, such as genetic engineering.

Faced with this uncertainty and complexity, Canadians are being asked to balance the relative merits and threats of bioproducts. The promises and issues raised by bioproducts and the shift towards a biobased economy make it critical that Canadians become well informed and participate in discussions about future directions and policies.

This chapter provides a summary of some of the issues raised by the development of bioproducts. It does not discuss these issues in detail, nor does it weigh the merits of the arguments introduced here. Readers interested in learning more about the issues and challenges of bioproducts are encouraged to contact the agencies and organizations listed in Chapter 7.

Crops for Food and Industry

The development of bioproducts is expected to increase industrial and commercial demands for agricultural crops and crop residues. It will require land use changes. For some people, this raises concerns about the amount of arable farmland that can be transferred to industrial biomass production without affecting the land needed to supply food.

For example, Cornell University Professor Lois Levitan concluded in a 2000 report that the amount of useable land on Earth may be barely adequate to feed the planet's six billion people, much less to provide biomass for industry. "I am skeptical," she wrote, "that a sustainable biobased economy is possible if it is expected to continue at the pace and consumption level of the fossil-based economy that industrial and post-industrial societies have come to know in this recent snatch of human history."

The issue is far from simple. Technological developments are making agricultural production more efficient at capturing the sun's energy and using available nutrients. These technologies hold out the promise that more produce can be grown faster on less available land, or on land previously considered unsuitable for conventional crop production. On the other hand, biomass as an industrial raw material is generally less concentrated per unit area than fossil fuels. As a result, compared

Source: © Jim Moyes (2002)

to conventional fossil fuel production, some crops for bioproducts can require more land and water, take more energy and chemical inputs to produce, collect and transport, and require more industrial processing steps to make into final products.

Whether or not bioproducts pose a significant threat to food supply is a question still to be answered. The Canadian Renewable Fuels Association has concluded that the maximum amount of grain (i.e., corn, wheat, barley, oats, rye) required to ensure that all gasoline used by Canadians contains 10 per cent ethanol would be eight to nine million tonnes annually — well under the 50 million tonnes of grain Canada typically produces. Moreover, a useful by-product of ethanol production is dried distillers grain, which can be used as a livestock feed. The large component of animal feed from ethanol production is what is termed a "co-product." Thus, co-products are an important consideration in exploring the value of a biobased economy.

Climate Change

Industrial bioproducts advocates, such as BioProducts Canada Inc., often point to climate change as an important reason to encourage the development of bioenergy and a biobased economy in Canada. They argue that using biomass as an alternative (or a complement) to fossil fuels and petrochemicals in industry will help reduce greenhouse gas emissions. Many biofuels, for example, produce less CO_2 than do fossil fuels when they are burned.

On the other hand, industrial demand for trees and crops for use as biomass raw materials could have a negative effect on climate change. For example, cutting old-growth forests that store large amounts of carbon to produce biomass crops and trees with lower carbon densities could result in a net increase in CO_2 in the atmosphere. Such valuable ecosystems need protection (as is happening in many countries). Similarly, the industrial production of biomass could require the increased production and use of fertilizers, herbicides and pesticides. These could contribute to increased greenhouse gas emissions and pollution.

Sustainable Development and Over-consumption

The shift to bioproducts could merely substitute biomass and biological processes for conventional non-renewable raw materials and manufacturing. Bioproducts would then fit into our existing system of industrial production. However, according to leading environmentalists, such as David Suzuki, the increasing demand for economic growth and the associated use of resources and energy may not be sustainable. While bioproducts and the biobased economy could still be growth-oriented, it remains a matter of debate as to whether or not the expanding consumption of resources will surpass the limits of the Earth's ecological productivity. As a shift, rather than a fundamental change, in our way of life, bioproducts could serve to mask the problem of over-consumption.

Some Benefits of Genetically Modified Organisms (GMOs)

- The first commercial drug was developed from this technology in 1982 and the first commercial crops were harvested in 1996.
- Major scientific review panels (e.g., American Medical Association, French Academy of Science, British Medical Association and Royal Society of Canada) have found no evidence of harm to humans from current genetically modified crops. Each crop gene combination, however, must be evaluated on its own risks.
- Genetically engineered crops can significantly reduce pesticide use and protect insect diversity.
- Genetically engineered crops can encourage no-till farming, which results in much greater formation of organic matter (i.e., a carbon sink).
- Genetically engineered crops, by increasing yields on prime agriculture lands, can reduce the need to grow crops on marginal land.
- Genetically engineered organisms are regulated by Health Canada and the Canadian Food Inspection Agency.

Source: Dr. G. Surgeoner, Ontario Agri-Foods Technologies, personal communication.

On the other hand, the development of bioproducts that encourage improved conservation and efficient technologies could be an important step towards sustainable development. It may be possible to develop bioproducts that enable industry to use both waste and renewable biomass instead of non-renewable fossil fuels, thus reducing the overall environmental "footprint" of economic activity.

The Use of Genetically Modified Organisms

Genetically modified organisms (GMOs) present both an opportunity and a challenge for bioproducts. While genetic engineering technology is only one tool used in the development of bioproducts, it has become a flashpoint of public concern. It was, for example, identified as a key issue by respondents interviewed for a 2002 Pollution Probe report, *Towards a Biobased Economy* (www.pollutionprobe.org/Publications/Biobased.htm).

Several industrial bioproducts and processes require changing the genetic blueprint of living things, such as transferring DNA between organisms. Genetic engineering is used to isolate and enhance the performance of micro-organisms and their catalyzing enzymes or to increase the production capacity and other characteristics of trees and crops.

Concerns about genetic engineering are influenced by the processes involved and by the ultimate use and fate of the genetically modified organisms. For instance, questions concerning the transfer of genetic material between organisms may be different from those raised by the manipulation of genes within a single species. Also, different issues arise for genetically modified organisms that are isolated from nature (e.g., enzymes used in contained laboratories and industrial environments) than for those planted in fields and forests. For example, one major environment group, the Sierra Club, takes no position with respect to genetic engineering done in labs or during industrial manufacturing. The group is, however, opposed to any "out-of-doors applications," arguing that the modified genes of fast-growing trees and disease-resistant crops may have adverse impacts on natural ecosystems and could escape to become incorporated in the genomes of related plants.

The Sierra Club of Canada argues that the conflict of interest inherent in government agencies that both promote biotechnology (e.g., Industry Canada, Natural Resources Canada) and regulate biotechnology (e.g., Health Canada and the Canadian Food Inspection Agency) is another reason to consider the technology to be inherently risky to the environment and health. Reports issued by the Royal Society of Canada and the Ontario Public Health Association in 2001 also criticized the biotechnology regulatory system in Canada as being inadequate to deal with many of the scientific, social and ethical issues associated with genetically modified organisms. The Government of Canada has developed an action plan to address the recommendations in the Royal Society Report and has committed to producing reports on the progress of the action plan (www.hc-sc.gc.ca/english/protection/novel_foods.html).

Other Environmental Considerations

Much attention is being focused on whether bioproducts can promise significant environmental benefits in addition to reduced energy consumption and greenhouse gas emissions. A recent report by the US Department of Energy concludes that, in general, a reduction in electricity generation, farming, transportation and the use of fossil fuels by industry could help reduce smog and acid rain-related emissions (nitrogen oxides and sulphur oxides), as well as emissions of greenhouse gases, such as CO_2, that contribute to climate change.

Some Concerns About Genetically Modified Organisms (GMOs)

- Genetically modified organisms (GMOs) could have unexpected and possibly lasting effects on natural ecosystems.
- GMOs could lead to the development of super-weeds and super-pests (more persistent plants and organisms) leading to increased or more toxic chemical use to try and contain them.
- GMOs could lead to genetic contamination of wild plants, as well as conventional and organic crops.
- GMOs could harm beneficial insects and other animals.
- GMOs could lead to loss of biodiversity.

Adapted from www.greenpeace.ca.

In some cases, such as pulp bleaching, bioproducts industries may use fewer toxic chemicals than conventional manufacturing. Similarly, some types of bioproducts are more readily degradable than their petroleum-based counterparts. Further, **biobased industries** that use agricultural, industrial and municipal wastes could reduce the need for **incinerators** and landfill sites. Meanwhile, bioproduct technologies can also be used in pollution prevention and contaminated site clean-up. Additionally, demand for biomass could result in a greater cultivation of carbon-fixing plants and organisms — thus removing CO_2 from the atmosphere.

Source: www.comstock.com/ca

These benefits are not assured, and many outstanding questions exist about the environmental impact of specific bioproducts and bioproduct technologies. One of these is whether bioproducts industries that depend on the large-scale harvest of trees and crops could demand large enough quantities of this living resource to outstrip the renewable supply, thus depleting forests and other ecosystems. The demand for parts of trees and crops that are usually left to decompose could leave soils starved for nutrients and reduce their value as carbon sinks. The Intergovernmental Panel on Climate Change notes that farms and communities in some areas could face shortages of water during periods of drought as planted stands of fast-growing trees demand more groundwater than other trees.

Loss of biodiversity is another concern. One of the greatest threats to the diversity of life on the planet is the conversion of land (wilderness and other natural ecosystems) to farmland and commercial forests. Industrial pressure to cultivate more biomass crops and trees for bioproducts could affect **critical habitat** for many species. Loss of habitat could cause a significant reduction in species diversity. For example, the diverse plant and animal communities of mixed wood forests could suffer if replaced by stands of fast-growing poplar.

Meanwhile, bioproducts that rely on biomass combustion could, if not managed properly, increase the amount of particulate emissions from industry, contributing to more industrial smog and pollution.

These issues are complex. Technology holds the promise of making biomass production and use more efficient, so industry demands can be met with less land and other resources than are currently required. Conservation, including recycling and the efficient use of waste, could also improve the availability of feedstocks and make industrial consumption of these resources more sustainable. Nevertheless, many questions remain about the environmental impacts of bioproducts, indicating that considerable research (including detailed resource and life-cycle assessments) is still required to find the answers.

Source: Corel Corporation

Economic Considerations

Bioproducts promise a variety of economic benefits. According to a report by the OECD, these could include improved investment in innovation, research and technology, improved long-term international competitiveness, and improved prospects for rural economies. Some researchers and advocacy organizations, such as BioProducts Canada, suggest that market advantage may be the primary driver for the shift to bioproducts and a biobased economy.

But, the economic implications of bioproducts and the biobased economy are far from fully understood, and some of these raise concerns. For example, there is a high potential that emerging bioproducts industries could concentrate on “least-cost” biomass crops instead of high-value ones, and could eliminate many of the expected economic benefits for farmers. Conversely, farmers may be unwilling to produce agricultural crops for an emerging bioproducts industry if market prices and consumer attitudes do not make it economically worthwhile.

A Challenge to Biotechnology Policy

Since 1993, the federal government has had a regulatory framework for biotechnology (in general) that sets standards for health and environmental protection, provides product evaluation and risk assessment guidelines (in line with international standards), and promises open and transparent enforcement of regulations. In the federal budget of 2000, the government set aside $90 million specifically to develop tools to more effectively regulate biotechnology, including training regulators and speeding up regulatory processes. While industry continues to lobby for faster and more favourable regulations for product approval, most Canadians — according to public opinion surveys — expect the federal government to put health and safety concerns first.

International trade issues and agreements, including those concerning farm subsidies and incentives for research and development, will become more complicated as global market mechanisms dictate the viability of agriculture, forestry and marine developments as sources of industrial biomass. Current trade agreements affecting Canada, such as the North American Free Trade Agreement (NAFTA) and requirements of the World Trade Organization (WTO), do not adequately account for the ecological impacts of a global bioproducts industry.

National and international agreements on safety, monitoring, processing, regulating intellectual property and government financing of bioproducts will face new challenges in addressing biobased technologies. Meanwhile, existing agreements that do apply to biotechnology, particularly with respect to safety and monitoring, have limited force. For example, the 2000 Cartagena Protocol on Biosafety to the Convention on Biological Diversity had been ratified by just 68 nations as of November 2003.

Another potential economic constraint to the development of bioproducts and a biobased economy is the shortage of highly skilled workers with multi-disciplinary training. Many bioproducts industries, for example, need employees cross-trained in the fields of engineering, biology and chemistry. Canadian university and research funding, however, continues to be delivered to investigators within particular disciplines, with little encouragement for multi-disciplinary study.

Social and Policy Considerations

The social impacts of various industrial bioproducts are far from known. An important concern for some, such as the Canadian Institute for Environmental Law and Policy, is the absence of a public forum in which the social merits and risks of bioproducts and bioproduct technologies can be adequately evaluated and debated.

Outstanding social questions include whether bioproducts will have a positive or negative impact on rural communities. The US Department of Energy argues that since biological resources used to fuel and feed bioproducts industries are found mainly in rural areas and the hinterlands, bioproducts and a biobased economy can be expected to benefit rural communities. Similarly, developing countries, whose economies rely heavily on one or more of these resources, could stand to benefit.

Some researchers, however, including Auburn University sociologist Conner Bailey, believe these potential benefits for rural areas raise the spectre of industrial control of agricultural and forested land to grow biomass as feedstock. Dynamic rural communities could become one-industry towns, subject to the same issues and vulnerabilities as other single-industry towns throughout North America.

The fact that land-use planning often takes place at a local, rather than a regional or national level further complicates this problem. According to Bailey, local authorities may miss the wider implications of large-scale industrial use of their lands. On the other hand, industry faces difficult hurdles attempting to simultaneously satisfy the various interests and levels of government involved in planning processes.

Ethical Considerations

The development of bioproducts — as the result of new technologies or existing technologies put to new uses — raises ethical and legal issues quite apart from their immediate environmental, economic and social consequences. These value-laden challenges influence the rules, principles and ways of thinking used to determine whether Canadian biotechnology policy is on a socially acceptable track.

Resolving ethical issues is rarely simple. For instance, how can the benefits to human society be balanced against the costs that might be imposed on the environment? The complexity and diversity of bioproducts adds another element of difficulty to ethical decision making in this area. The pace of change in bioproducts development is yet another confounding factor.

Becoming an Informed Citizen on Bioproducts

- Read arguments both for and against biotechnology and bioproducts.
- Judge information sources (e.g., industry/activist sites, as well as government reports and peer reviewed scientific publications).
- Recognize that each bioproduct must be judged on its own risks and benefits. Blanket statements may be inaccurate.
- Consider full life-cycle analysis from energy inputs, co-products produced and final disposal of products.
- Understand the current product production system for comparative purposes (e.g., full life-cycle assessment of fossil fuel-based products versus bioproducts).
- Consider the probability, not just the possibility, of risk — “can” and “may” statements are always possible, but probability must also be considered.
- Understand who regulates the use of bioproducts and how (i.e., role of regulatory agencies).

Source: Dr. G. Surgeoner, Ontario Agri-Food Technologies, personal communication.

Organizations involved in the ethical consideration of research and development that could have an impact on bioproducts include the Canadian Biotechnology Advisory Committee (CBAC) — an agency that provides advice to the federal government on ethical, social, economic and regulatory aspects of biotechnology — and the International Bioethics Committee of UNESCO.

Many of the ethical considerations facing environmental biotechnology research are discussed in a primer for scientists published in 2003 by the Ottawa-based Institute on Governance (www.iog.ca). Some ethical questions arising from the development of bioproducts include balancing precaution against inaction in the development of technologies (affecting innovation), establishing a system to determine whether the means of research and development for bioproducts is morally justifiable (with respect to humans, animals and ecosystems), and assessing the potentially conflicting interests and obligations of bioproducts researchers relative to their funding sources.

Technical Considerations

While many bioproducts have existed for a long time, many more products and the technologies that produce them are being developed. University and industry researchers continue to explore the scientific, technological and commercial possibilities presented by biological materials. Bioproduct technologies will clearly continue to present new opportunities and challenges for Canadians well into the future.

A Perspective on Biomass and the Biobased Economy

Biomass is one of the more abundant, underutilized and renewable sources of energy, available in relative large quantities across Canada. Organic materials such as agriculture, aquaculture and forestry wastes, biosolids (from municipal waste water treatment plants and of animal origin), municipal solid waste and fast growing plants have the potential to be converted into biochemicals or clean burning fuels in an environmentally sustainable manner. By utilizing readily available quantities of organic material for energy generation, biomass technologies can help supplant Canada's current reliance on foreign oil and protect the environment by reducing greenhouse gases while limiting the environmental damage associated with extraction, refining and production of fossil fuels. Opportunities exist across Canada to capture and harness the energy potential of this resource, particularly in rural areas with significant quantities of agro-forestry and marine biomass infrastructure in place. But most biomass users today rely upon inefficient and sometimes highly polluting ways of generating, converting and utilizing biomass for energy production.

Bioenergy production involves an incredibly complex mix of feedstocks and conversion technologies, each with its own set of impacts and benefits. There are very conflicting messages on even the most environmentally benign options. In addition, unsustainable biomass harvest and land use practices may cause a depletion of soil nutrients and organic matter essential for the sustainable growth of agricultural and forest species and release soil carbon to the atmosphere. Accelerated and poorly managed cultivation and harvesting of biomass and the conversion of natural ecosystems/marginal lands to fuel farms may also act to increase global warming and degrade the environment.

Realization of the tremendous potential contained in biomass across Canada may be impeded by serious data gaps in our understanding of the following dimensions of biomass utilization:

- The need for a commonly accepted definition of biomass by government, industry and academia;
- The need for regulatory clarity at all levels as to what legislation will be triggered by the largely novel uses and new technologies likely to be involved in biomass generation, conversion, downstream processing, and utilization;
- The absence of ecological baseline data on biomass life cycle assessment under representative Canadian conditions;
- The continuing fractious debate on the role of rDNA applications in agriculture, forestry and marine environments; and,
- The current absence of a scientifically validated framework in Canada to evaluate a range of biobased products for performance, efficiency and overall sustainability.

Source: Dr. T. McIntyre, Environment Canada, personal communication.

Chapter 7

Chapter 7

How Will Bioproducts Affect You?

This Primer on Bioproducts is intended to promote a greater understanding of the use of biomass and biological tools as an alternative or a complement to fossil fuels and conventional industrial processes. It describes what bioproducts are, why they are being developed now, and where to find them.

The Primer also emphasizes the importance of being equipped with at least an introductory understanding of the implications of bioproducts in Canada. As more industries and businesses adopt these technologies, Canadians will be asked to debate their benefits and risks. Readers will have to make decisions about bioproducts, while being faced with difficult issues and complex science.

The opportunities for Canadians to make these decisions are many. Choosing whether or not to buy bioproducts is among the most powerful ways to express your opinion. Regulations and incentives aside, the success or failure of bioproducts may ultimately be decided by consumers at store shelves and gasoline pumps.

To learn more about bioproducts, consumers can watch for labels on the household products they buy. In some cases, labels help to distinguish between bioproducts and the resources and technologies — such as genetic engineering — they rely on. They may also indicate certain "eco-standards" of being "green," "sustainable" or "environmentally friendly." At the present time, labelling of products containing genetically modified organisms is not required in Canada (although standards are being developed for the voluntary labelling of foods derived from biotechnology).

Readers are also encouraged to access other resources — government and non-government organizations, researchers and educators, industry associations and representatives — to get information that explains the science and technology, the environmental and social impacts, the costs, and the ethical considerations related to bioproducts.

Pollution Probe is dedicated to ensuring that governments and industry implement policies and programmes that lead to a cleaner and safer environment. The support of an informed and active public is essential to this mission. BIOCAP Canada is committed to providing the research insights and technologies to inform policy and investment decisions to support the sustainable use of biological systems to address climate change. This Primer is an important part of the public education and outreach program of both organizations. Our main message is that you should understand the issues, ask the questions you consider to be important, and, if you are concerned about bioproducts as an environmental issue, get involved!

For Further Information

(all websites were accessed for verification on May 28, 2004)

To voice your concerns in the public discourse about bioproducts, you can contact or become involved in any of the groups and agencies at the leading edge of the debate about these products and technologies. For further information about what you can do, some relevant organizations are listed below:

AboutBioDiesel.com — www.greenincubator.com/aboutbiodiesel

Agriculture and Agri-Food Canada — www.agr.gc.ca

American Biomass Association — www.biomass.org

BC Biotech — www.bcbiotech.ca

BioAlberta — www.bioalberta.com

BioAtlantech — www.bioatlantech.nb.ca

BIOCAP Canada Foundation — www.biocap.ca

Biomass Energy Research Association — www.bera1.org

BioProducts Canada Inc. — www.bio-productscanada.org

BioQuébec — www.bioquebec.com

BIOTECanada — www.biotech.ca

Canadian Biotechnology Advisory Committee — www.cbac-cccb.ca

Canadian Chemical Producers' Association — www.ccpa.ca

Canadian Forest Service (CFS) — www.nrcan.gc.ca/cfs-scf

Canadian Institute for Environmental Law and Policy — www.cielap.org

Canadian Renewable Fuels Association (CRFA) — www.greenfuels.org

Canadian Renewable Energy Network — www.canren.gc.ca

Canadian Rural Revitalization Foundation — www.crrf.ca

Centre Quebecois de Valorixation des Biotechnologies — www.cqvb.qc.ca

Contact Canada — http://contactcanada.com

Council for Biotechnology Information — www.whybiotech.ca

David Suzuki Foundation — www.davidsuzuki.org

Environment Canada, Environmental Technology Advancement Directorate — www.ec.gc.ca/etad

Friends of the Earth Canada — www.foecanada.org

Greenpeace International — www.greenpeace.org

Industry Canada, Life Sciences Branch — http://strategis.ic.gc.ca/sc_indps/sectors/engdoc/lsbe_hpg.html

Intergovernmental Panel on Climate Change — www.usgcrp.gov/ipcc

National Climate Change Process — www.nccp.ca/NCCP/index_e.html

National Research Council — www.nrc-cnrc.gc.ca

Natural Resources Canada — www.nrcan.gc.ca

Ontario Agri-Food Technologies — www.oaft.org

Ottawa Life Sciences Council — www.olsc.ca/index.php

Pollution Probe — www.pollutionprobe.org

Royal Society of Canada — www.rsc.ca

Sierra Club of Canada — www.sierraclub.ca

US National Biobased Products and Bioenergy — www.bioproducts-bioenergy.gov

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Canadian Renewable Fuels Association. www.greenfuels.org.

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Glossary of Terms

Anaerobic digestion: Decomposition process using micro-organisms that live and reproduce in an environment void of "free" or dissolved oxygen to decompose and stabilize organic solids or biosolids. This process generates biogas.

Bacteria: Members of a group of microscopic organisms with a very simple cell structure. Some manufacture their own food, some live as parasites on other organisms, and some live on decaying matter.

Biobased economy: An economy in which most industry, commercial and economic activity depends on renewable biomass and biological processes to supply energy, chemicals, products and services. Bioproducts are to the biobased economy what fossil fuels and petrochemicals are to the current "fossil fuel economy" that now provides about 80 per cent of the world's energy needs.

Biobased industries: Industries that rely on biological sciences in combination with process engineering to produce a wide variety of industrial products from renewable organic resources. Biobased industrial products include liquid fuels, chemicals, lubricants, plastics and building materials.

Biodegradable: Capable of decomposing rapidly under natural conditions (usually by the action of micro-organisms).

Biodiesel: An alternative fuel made from plant oils that can be used in a conventional diesel engine.

Biodiversity: The relative abundance and variety of plant and animal species and ecosystems within particular habitats.

Bioenergy: Useful, renewable energy produced from organic matter; the conversion of complex carbohydrates in organic matter to energy. Organic matter may either be used directly as a fuel or processed into liquids and gases.

Biofuels: Fuels made from cellulosic and other types of biomass resources. Biofuels include ethanol, biodiesel and methanol.

Biogas: A combustible gas derived from decomposing biological waste. Biogas typically consists of 50 to 60 per cent methane.

Biomass: Renewable organic matter. Biomass includes forest products, plants, agricultural crops and wastes, wood and wood wastes, animal wastes and aquatic plants, as well as organic fractions of municipal and industrial wastes.

Bioproducts: Commercial or industrial products that rely on energy, chemicals or processes available from living organisms. If properly developed, the sources of bioproducts are renewable and can replenish themselves over and over again using energy from the sun. Bioproducts are a complement or an alternative to the industrial products manufactured using petrochemicals or fossil fuels.

Bioremediation: The use of micro-organisms to remedy environmental problems, rendering hazardous wastes non-hazardous.

Biotechnology: The application of biology and biological techniques to develop products and industrial processes.

Carbon: A common chemical element that plays a critical role in the chemistry of life; it is incorporated into biological processes and biomass through photosynthesis.

Carbon cycle: The flow of carbon from an inorganic state to an organic state and back again.

Carbon dioxide (CO_2): A common colourless and odourless gas produced during respiration, combustion and the decomposition of organic material. It is taken up by plants as part of the solar energy trapping process of photosynthesis.

Carrying capacity: The number of people (or their industries) that an area can support, given the quality of the natural environment and the level of technology of the population.

Catalysts: Agents (such as enzymes or metallic complexes) that facilitate a reaction, but are not themselves changed during the reaction. They may or may not be consumed during the reaction.

Cells: The smallest structural units of a living organism that can grow and reproduce independently.

Cellulose: A tough carbohydrate found in plants, cellulose gives strength and structure to cell walls.

Cellulose-based: Biomass with a high cellulose content, or bioproducts derived from cellulose.

Co-firing: The practice of introducing biomass into the boilers of coal-fired electricity plants. Adding biomass as a source of fuel helps to reduce the use of coal.

Combustion: Burning. The transformation of biomass fuel into heat, gases and inorganic ash through chemical combination of hydrogen and carbon in the fuel with oxygen in the air.

Coppiced: To cut back, so as to re-grow in the form of a forest originating mainly from shoots or root suckers, rather than seed.

Cost-effective: A term describing a resource or process that is economical in terms of tangible benefits produced by money spent.

Critical habitat: Geographic areas with the physical and biological features essential to a species.

DNA (Deoxyribonucleic acid): The molecule that carries the genetic information for most living systems. The DNA molecule consists of four bases (adenine, cytosine, guanine and thymine) and a sugar-phosphate backbone, arranged in two connected strands to form a double helix.

Ecosystem: The system of interactions between living organisms and their environment.

Emissions: Waste substances released into the air, water and soil.

Enzymes: Protein catalysts that facilitate specific chemical or metabolic reactions necessary for cell growth and reproduction, as well as other applications.

Eutrophication: The accumulation of excessive nutrients in lakes, streams and other surface water bodies often associated with enrichment by nitrogen and phosphate run-off from fertilizers. It causes excessive algal growth and reduces available oxygen, often making the water uninhabitable for other species.

Feedstock: Input material converted to another form or product.

Fermentation: An enzymatically controlled anaerobic breakdown of an energy-rich compound (such as a carbohydrate to carbon dioxide and alcohol, or to an organic acid).

Fossil fuel: Solid, liquid or gaseous fuels formed in the ground after millions of years by chemical and physical changes in plant and animal residues under high temperatures and pressures. Oil, natural gas and coal are fossil fuels.

Fuel cell: A device that converts the energy of a fuel directly to electricity and heat, without combustion.

Gasification: A chemical or heat process used to convert a solid fuel to a gaseous form.

Gene: A segment of chromosome. Some genes direct the syntheses of proteins, while others have regulatory functions.

Genetic engineering (genetic modification): The applied techniques of genetics and molecular biotechnology that manipulate an organism's genetic material to make the organism capable of producing new substances, performing new functions or blocking the production of substances. Genetic manipulation involves eliminating, modifying or adding copies of specific genes (from other organisms) to change one or more of its characteristics. Also called "gene splicing," "recombinant DNA (rDNA) technology" or "genetic modification."

Greenhouse gas (GHG): Any gas that traps the heat of the sun in the Earth's atmosphere, producing the greenhouse effect. The two major greenhouse gases are water vapor and CO_2. Other greenhouse gases include methane, nitrous oxide and fluorinated gases (i.e., CFCs, HCFCs, HFCs, PFCs and SF_6).

Incinerator: Any device used to burn solid or liquid wastes as a method of disposal. In some incinerators, provisions are made for recovering the heat produced.

Kyoto Protocol: An international agreement extending the commitments of the United Nations Framework Convention on Climate Change to include targets for future greenhouse gas (GHG) emissions by developed countries. Canada's commitment under the Kyoto Protocol is to reduce net GHG emissions to six per cent below 1990 levels between 2008 and 2012. The protocol was developed in 1997 in Kyoto, Japan.

Landfill: Land where household waste, industrial waste and/or treated domestic sewage biosolids are disposed.

Landfill gases: Gases generated by decomposition of organic material at landfill disposal sites. Landfill gas is approximately 50–60 per cent methane, 40–50 per cent CO_2, and less than one per cent hydrogen, oxygen, nitrogen and other trace gases.

Megawatt (MW): An electrical unit of power that equals one million Watts (1,000 kW).

Micro-organism: Any organism that can be seen only with the aid of a microscope.

Nanotechnology: Atomic- or molecular-scale technology developed at dimensions of less than 10 millionths of a metre (100 nanometres).

Organic: Derived from living organisms, containing naturally occurring carbon (and hydrogen) compounds.

Petrochemicals: Chemicals derived from oil, natural gas or other fossilized hydrocarbons.

Photosynthesis: The conversion by plants of light energy into chemical energy (carbohydrates are made from CO_2 and water in the presence of chlorophyll and sunlight). The chemical energy is then used to support the biological processes of the plants and animals that eat them.

Protein: An organic molecule composed of amino acids that are responsible for cell maintenance and growth.

Pyrolysis: The thermal decomposition of biomass at high temperatures (greater than 200°C) in the absence of air. The end product of pyrolysis is a mixture of solids (char), liquids (oxygenated oils), and gases (methane, carbon monoxide, and CO_2), with proportions determined by operating temperature, pressure, oxygen content and other conditions.

Sequestration, sequestered: The long-term storage of carbon in the terrestrial biosphere, underground, or in the oceans, isolating the carbon from the carbon cycle to ensure the build up of CO_2 (the principal greenhouse gas) in the atmosphere will be reduced.

Sustainable development: According to the 1987 UN World Commission on the Environment and Development, "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Syngas: A "synthesis gas" consisting mainly of carbon monoxide (CO) and hydrogen (H) that is created by the gasification of liquid or solid biomass. Syngas is used for producing power or hydrogen, methane and other fuels.

Thermal depolymerization: A process that uses pressure and heat to reduce biomass (usually organic waste material) into light crude oil by breaking down long-chain polymers of hydrogen, oxygen and carbon into short-chain petroleum hydrocarbons. The process, also called thermochemical conversion or a thermal conversion process, is thought to mirror the natural geological process that produces fossil fuels.

Thermochemical processing: The chemical processing of biomass at high temperatures to produce fuels, such as biogas or bio-oil. Pyrolysis and gasification are examples of thermochemical processes.

Thermo-chemistry: The branch of chemistry that explores the interaction of heat and chemical reactions.

Toxic substance: A chemical or material harmful to people, plants and animals.

Turbine: A machine of rotary blades and a drive shaft that uses the energy of a stream of fluid (usually water or steam) to power a generator that creates an electromagnetic field, transforming the mechanical energy into electricity.

Yeast: A general term for single-celled fungi that reproduce by budding. Some yeasts can ferment carbohydrates (starches and sugars).

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